Electrostatic methods: EFM, SPFM, KPFM (KFM)

The Kelvin method

In this method we measure the current induced in the wire connecting two materials of difference work functions when the distance between the two is varied in a periodic way. The current is due to the change in capacitance and the contact potential difference:

$$Q = C.V = C(z).(\phi_1 - \phi_2)$$

[$= \varepsilon S/z.(\phi_1 - \phi_2)$ for a parallel plate capacitor]

Modulating the distance z, for example with a sine wave: $z(t) = z_o + z_1.\sin(\omega t)$

$$I(t) = \partial Q/\partial t = \partial C/\partial z.\ z_1.\omega.\cos(\omega t).(\phi_1 - \phi_2) = I_o.\cos(\omega t)$$

The measurement consists in applying a voltage difference between the two such that the current I is zero:

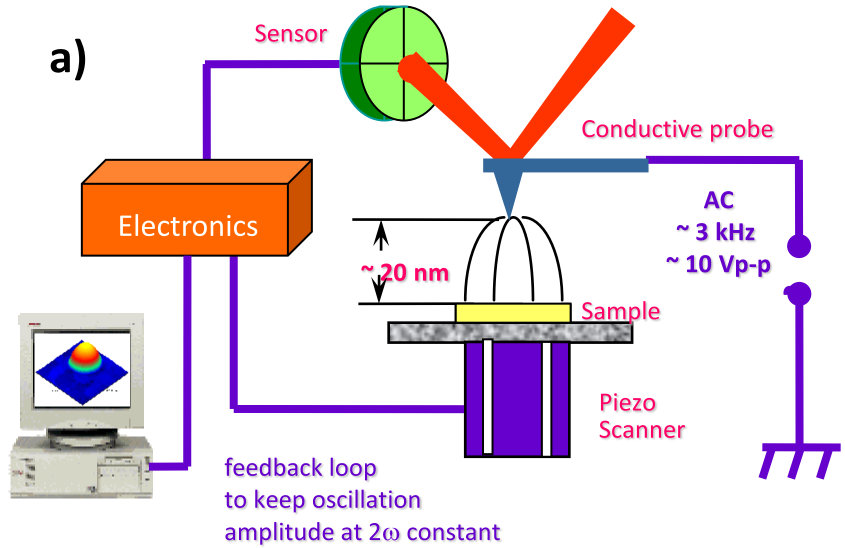
$$I_o = 0 = \partial C/\partial z.\ z_1.(\phi_1 - \phi_2 + \Delta V)$$

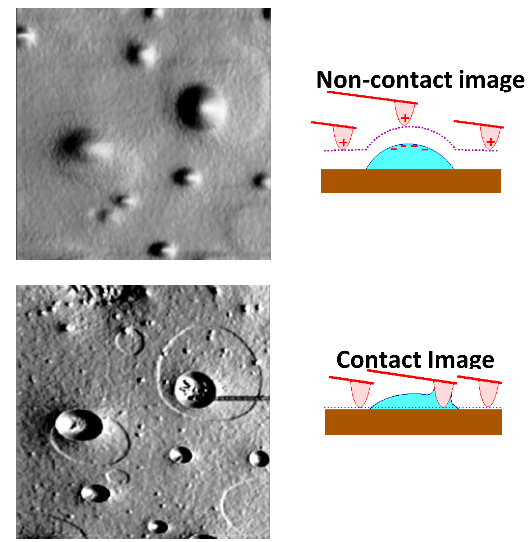
That gives $\phi_1 - \phi_2 = -\Delta V$

We will later see how this technique can be implemented in an Atomic Force Microscope. In this way we will be able to “map out” the local value of $\phi(x,y)$ with very high spatial resolution (nm).

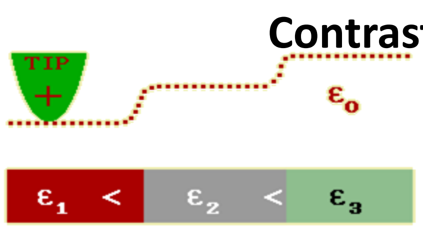
Electrostatic forces: Scanning Polarization Force Microscopy

a)

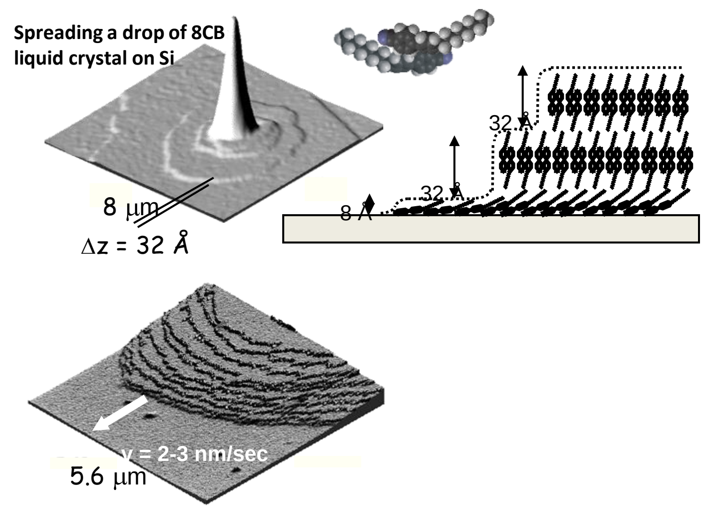




b)



$$F_{pol} \approx \frac{\varepsilon_i - \varepsilon_o}{\varepsilon_i + \varepsilon_o}$$



c) **Dielectric Spectroscopy**

Freq. Dependence of $\varepsilon(\omega)$

Modulation techniques in SPFM

Electrostatic force for a dielectric material

$$F = -\frac{1}{2} \times \frac{\partial C}{\partial z} \times (V - \varphi)^2 = \tilde{\varepsilon}(\omega) \times (V - \varphi)^2$$

Modulating $V = V_0 + V_1 \sin\omega t$

$$F_{dc} = \tilde{\varepsilon}(\omega) \times f(z) \times (V_0 - \varphi)^2$$

Topography + surface potential

$$F_{\omega} = \tilde{\varepsilon}(\omega) \times f(z) \times (V_0 - \varphi) \times V_1$$

Surface potential

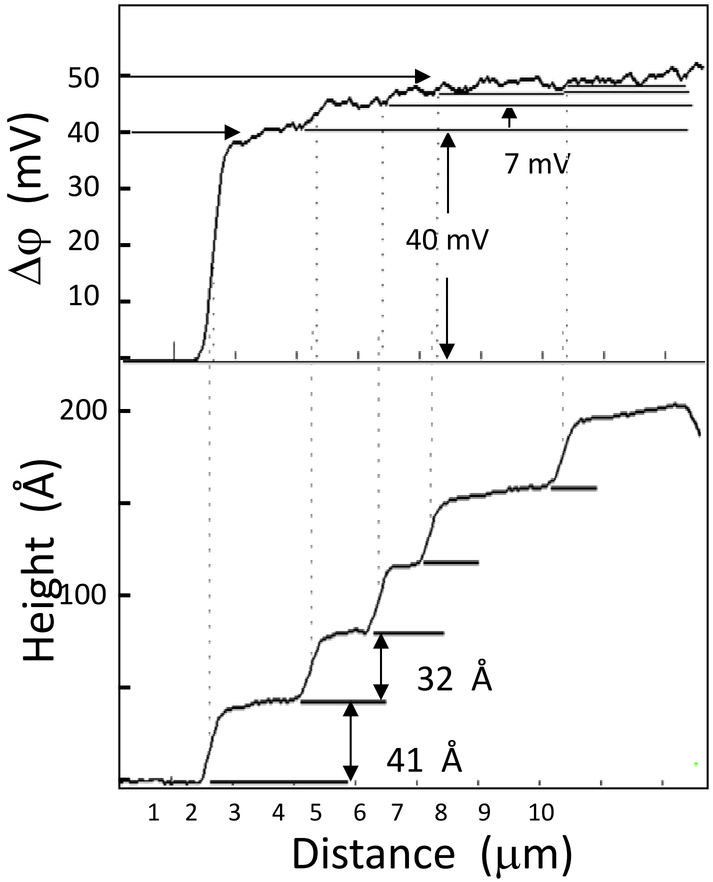
$$F_{2\omega} = \tilde{\varepsilon}(\omega) \times f(z) \times V_1^2 \longrightarrow$$

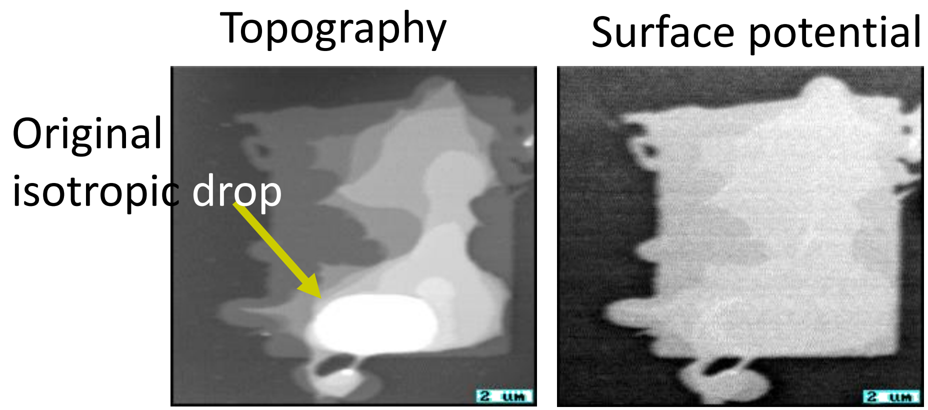
Topography

C. Schoenenberg and S.F. Alvarado, *Phys. Rev. Lett*. 65 3162 (1990)
H. Yokoyama and T. Inoue, *Jpn. J. Appl. Phys.* 32 L1845 (1993)

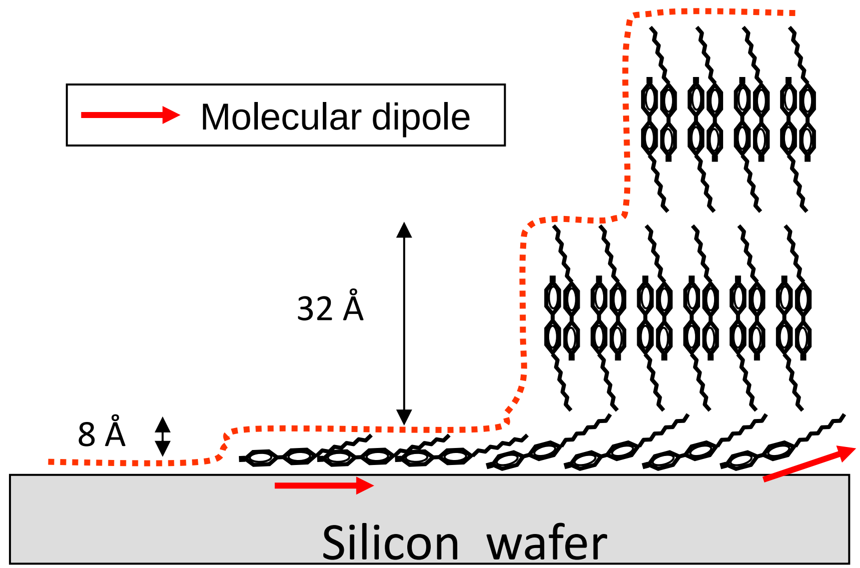
Measuring contact potentials: Kelvin Probe Microscopy

Liquid crystal 8CB:



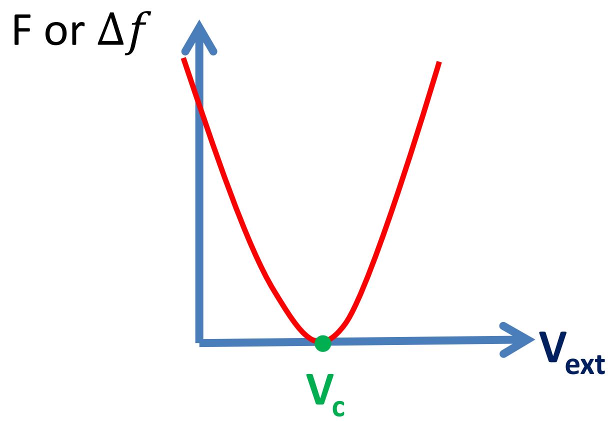


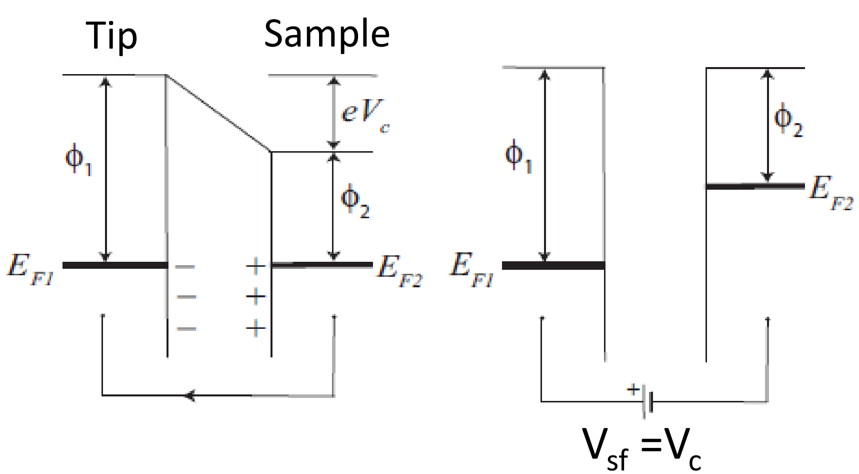
Smectic bilayers on top of a monolayer

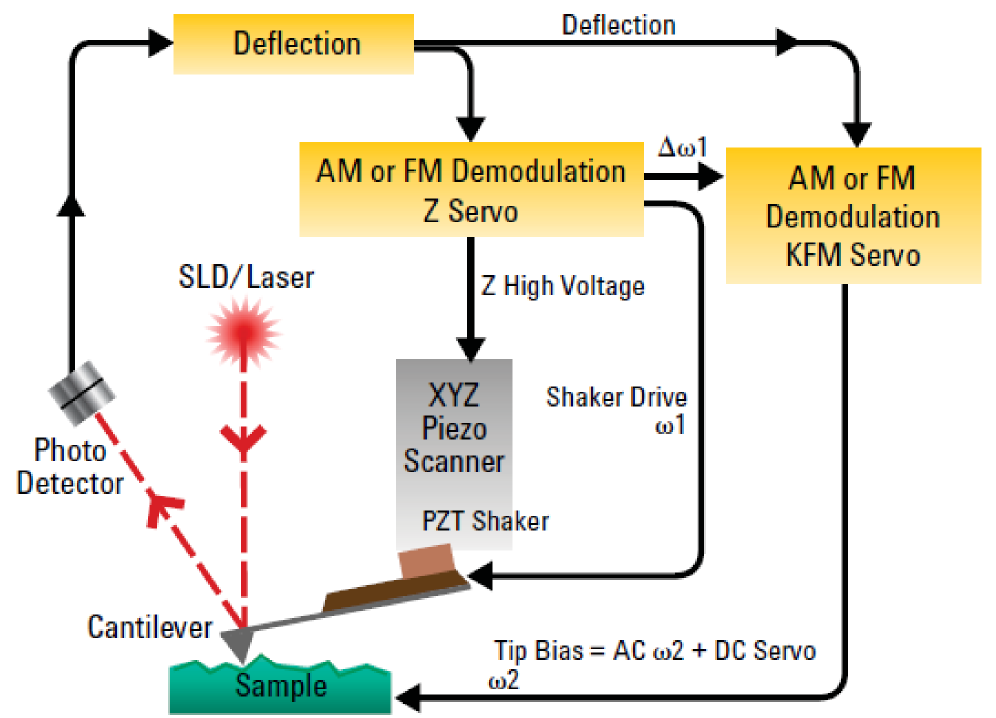


Wetting and molecular orientation of 8CB on silicon substrates
L. Xu, M. Salmeron and S. Bardon
Phys. Rev. Lett. 84, (7) 1519 (2000)

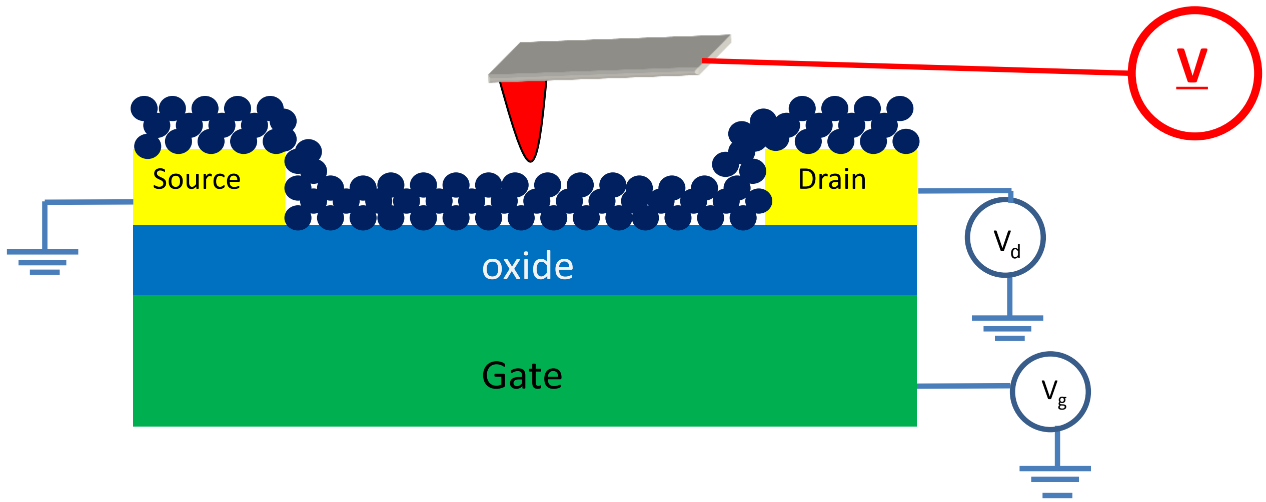
Kelvin Probe Force Microscopy

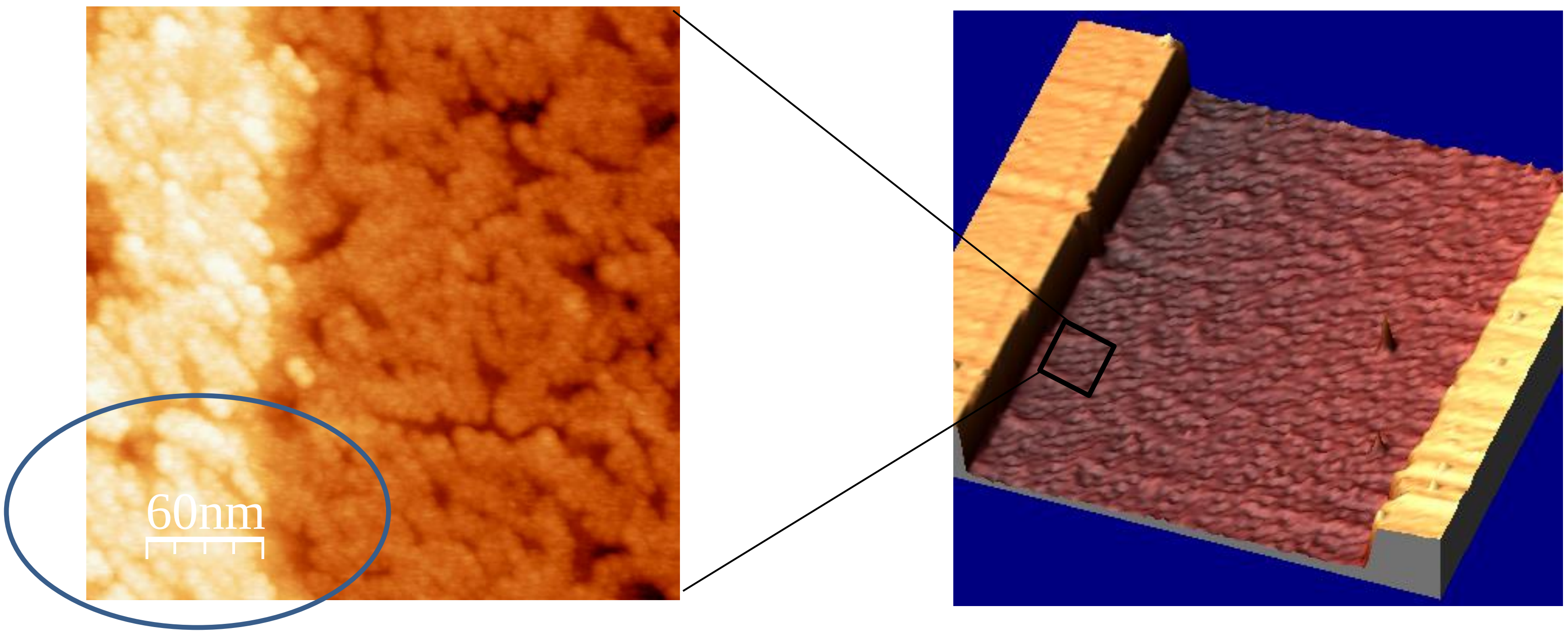




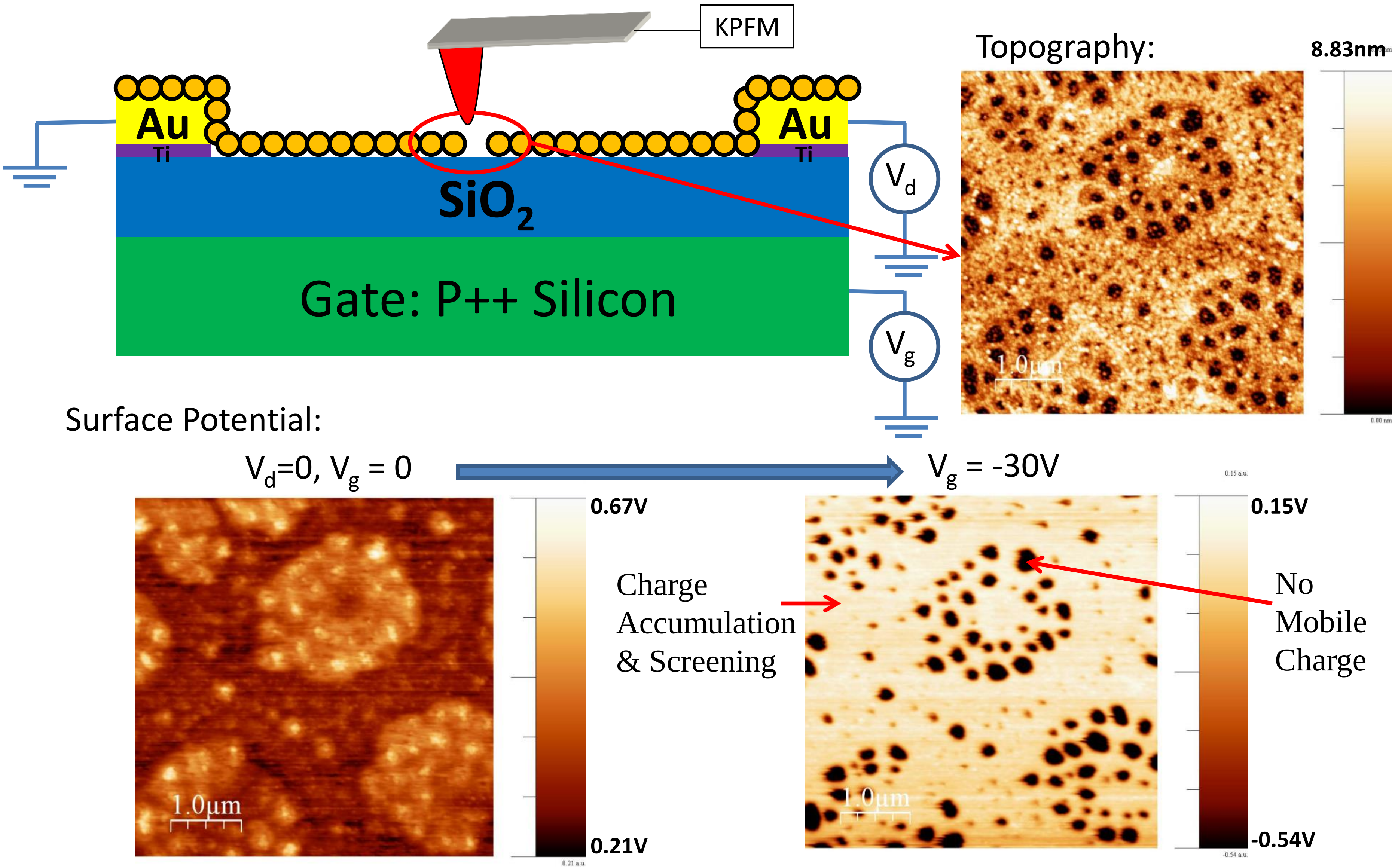


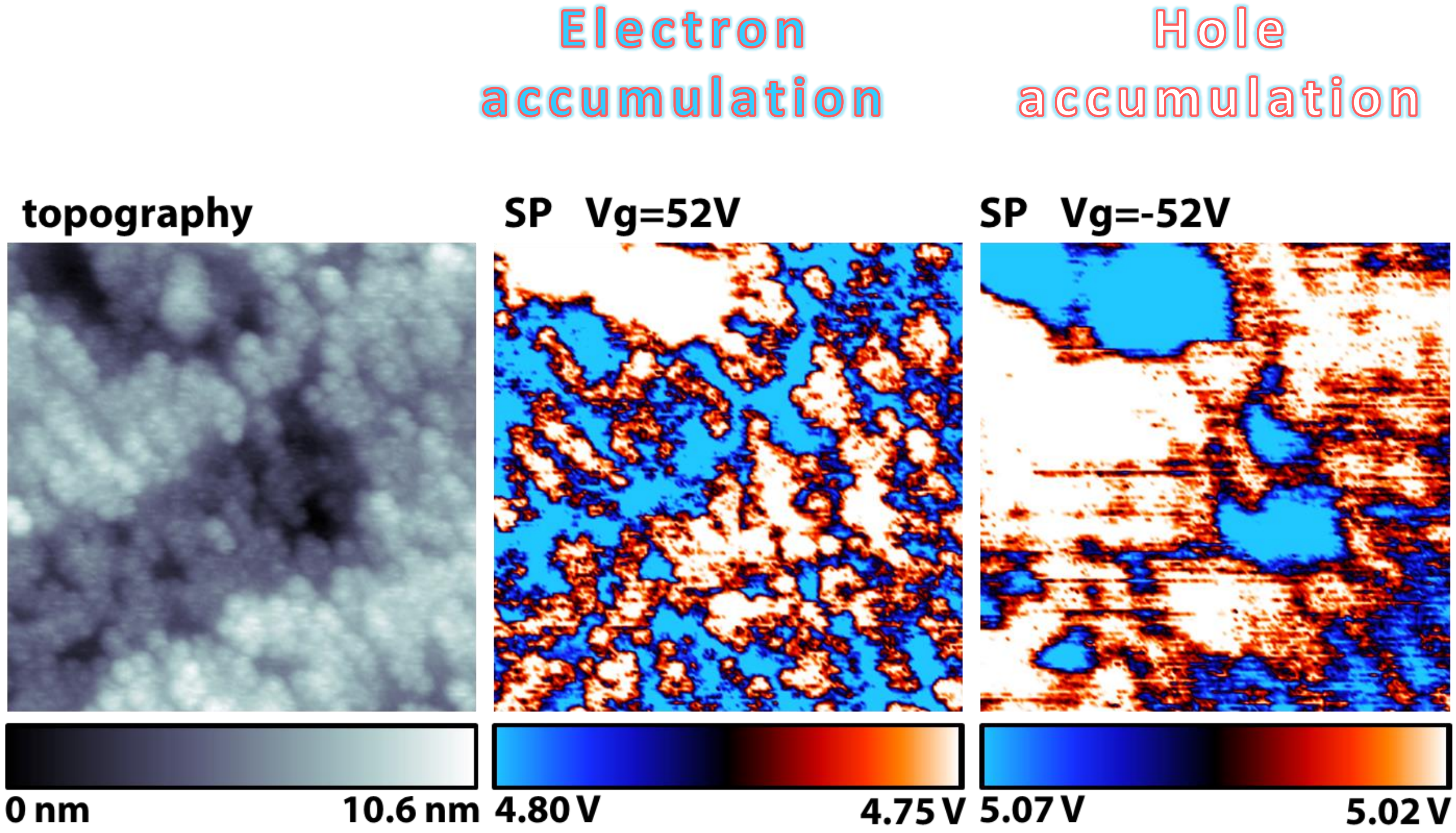
Kelvin Probe Force Microscopy





Surface Potential Imaging of PbS




Electron accumulation
Hole accumulation
topography
SP Vg=52V
SP Vg=-52V
0 nm
10.6 nm
4.80 V
4.75 V
5.07 V
5.02 V